AMEGO: An All-Sky Medium Energy Gamma ray Observatory

Instrumentation and Mission Overview

High Energy Space Environment Branch
Space Science Division

Richard S. Woolf
on behalf of the AMEGO team

January 10th 2018

AMEGO at the 231st AAS

http://asd.gsfc.nasa.gov/amego

Monday

Gamma-SIG at 11:00 am (MD Ballroom 3)

Tuesday

Poster Session at 5:30 pm

MeV Emission from Local Seyfert Active Galaxies (E. Mullin)

Wednesday

Talk at 10:00 am (Maryland B)

Polarization Observations of Fermi Blazars (B. Rani)

Wednesday

Splinter at 1:00 pm (National Harbor 8)
https://asd.gsfc.nasa.gov/conferences/aas2018/

Astrophysical Extremes and Life Cycles of the Elements (A. Harding, D. Hartmann, J. Racusin, A. Fabian, R. Woolf, & T. Linden)

Poster Session at 5:30 pm

Fermi-LAT VIP AGN (D. Thompson)

GRBs and GW Counterparts with AMEGO (J. Racusin)

Neutrino Astrophysics in the MeV Band (R. Ojha)

Thursday

iPoster Session at 9:00 am

Development and Testing of the Tracker (S. Griffin)

Poster Session at 5:30 pm

Exploring Dark Matter (R. Caputo)

CsI Calorimeter Development for AMEGO (J. E. Grove)

Friday

Talk at 2:10 pm (Potomac C)

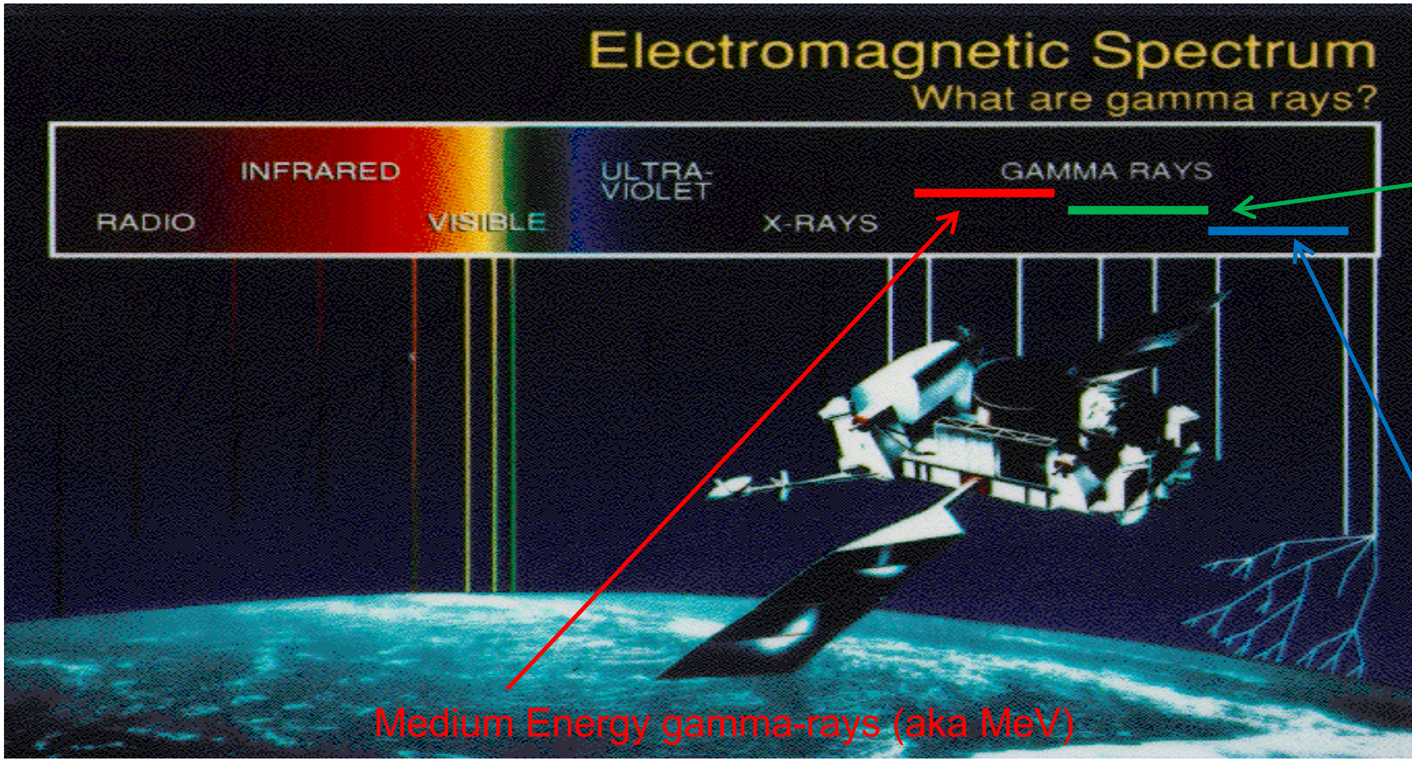
Advancing the MeV Frontier with AMEGO (D. Hartmann)

AMEGO Team*

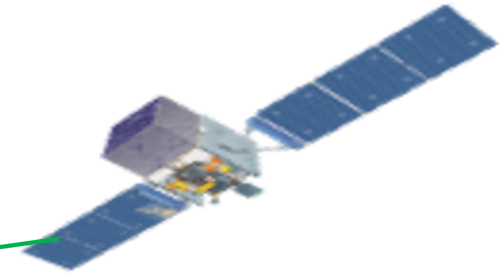
NASA/GSFC, NRL, GWU, Clemson, UC Berkeley, SLAC, Wash U, UNH, NASA MSFC, UAH, USRA, OSU, UIUC, UNLV, U Del, Georgia Tech, UC Santa Cruz, Stanford, Argonne Nat'l Lab, UMD, UMBC, NWU, LANL, Univ. Padova/INFN, Rice, Universidad Autonoma de Madrid, University of Trieste, Hiroshima University.

*https://asd.gsfc.nasa.gov/amego/team.html

Gamma-ray Astrophysics



Medium Energy gamma-rays (aka MeV)

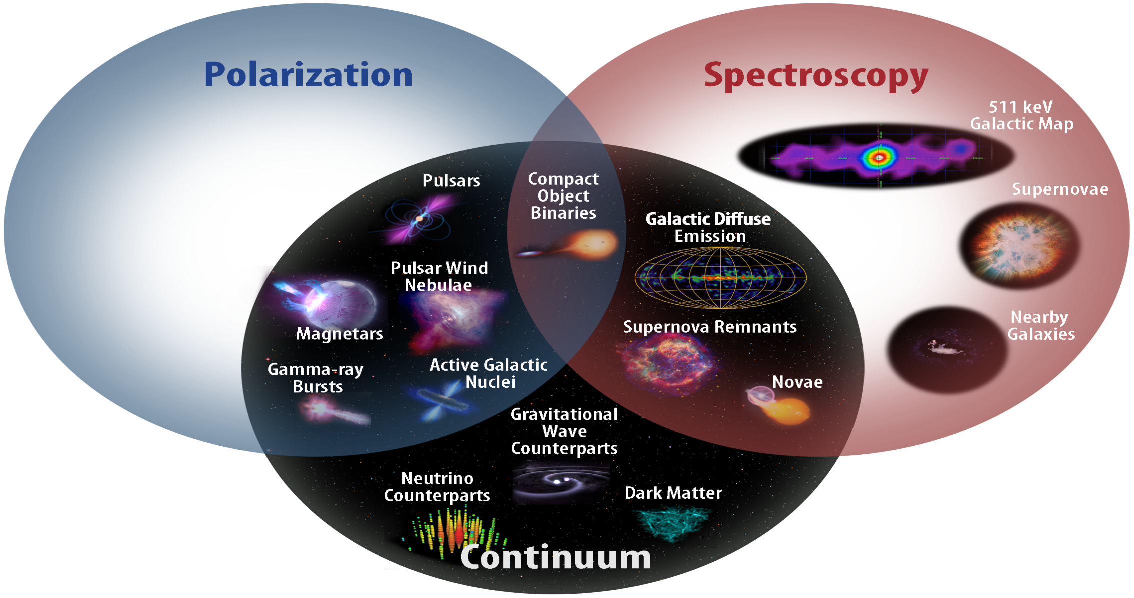


High Energy gamma-rays
(aka GeV)

Very High Energy (VHE)
gamma-rays (aka TeV)

Why measure gamma rays?

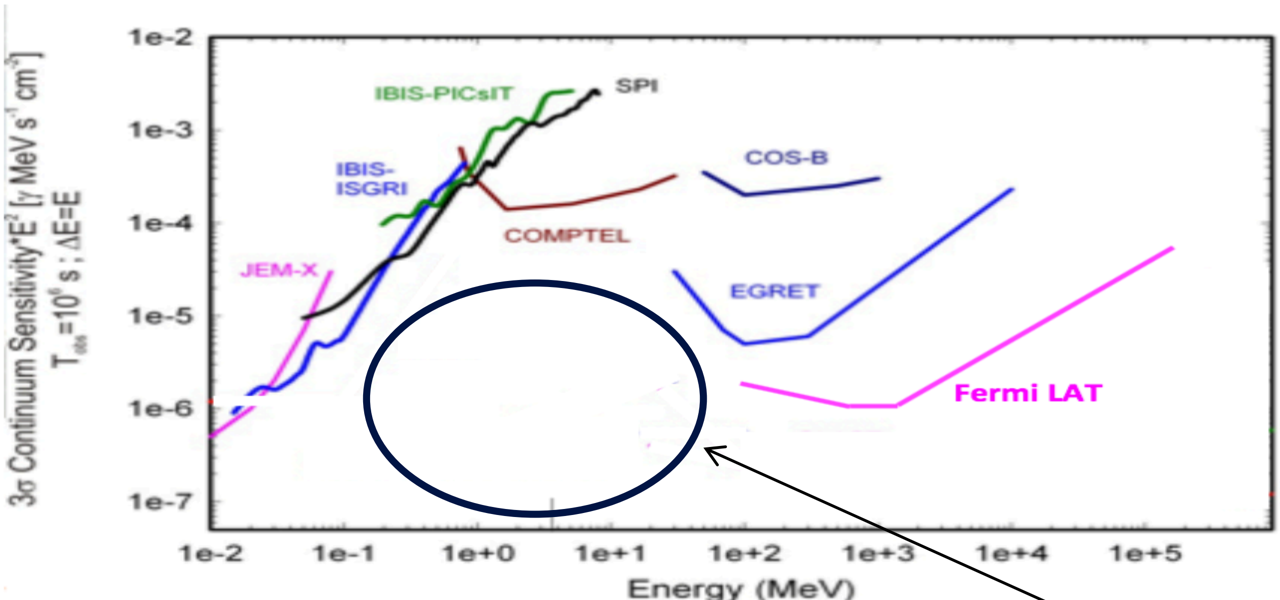
- High energy photons are produced in different physical processes and carry key information regarding the underlying process.
- Photons propagate through Universe unaffected by magnetic fields and continuous energy losses, allowing for direct measure of their origination point and spectrum at the source.



AMEGO will provide three new capabilities in MeV astrophysics:

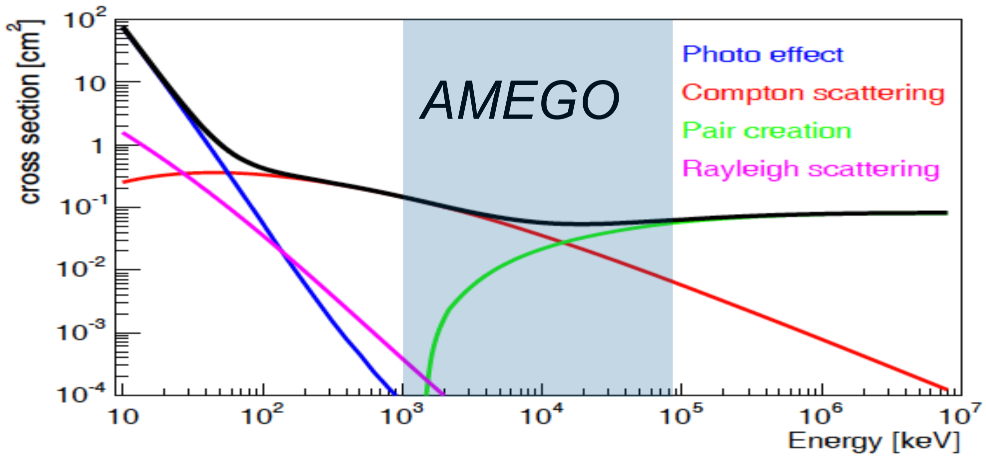
- Sensitive continuum spectral studies
- Polarization
- Nuclear line spectroscopy

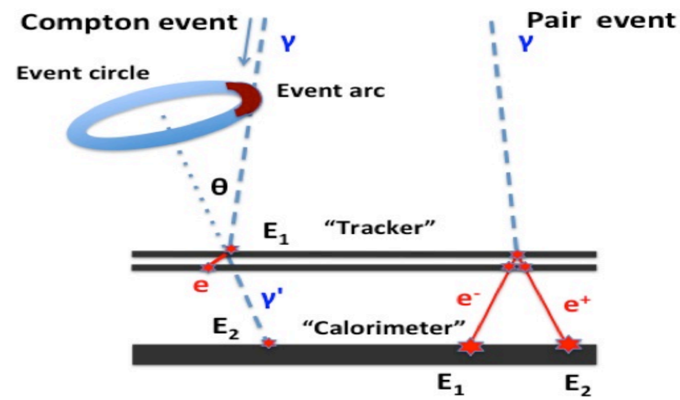
MeV-GeV sensitivity



- There is potential discovery space in this so-called "MeV gap."
- What are the reasons for this gap?

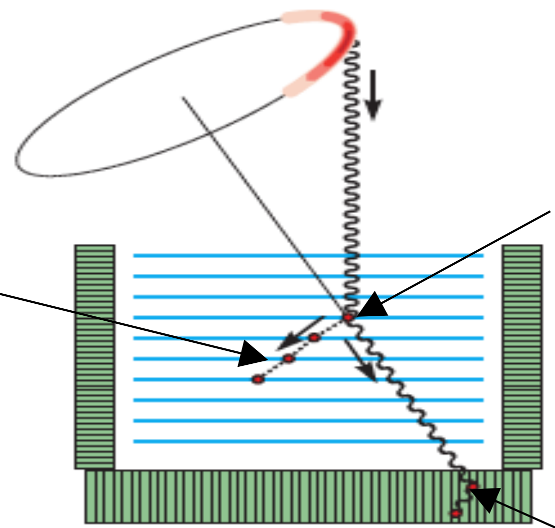
Detecting MeV gamma rays





- Between 0.1 to ~100 MeV two interaction processes compete
  - Compton scattering and pair-production
- To fill the "MeV Gap" we need to consider both Compton scattering and Pair Production
- At low energy pair-production components (e^+ and e^-) suffer large multiple scattering, causing large uncertainty in the incident photon direction reconstruction

Compton Scattering



- Need to measure location of the Compton interaction and absorption of the scattered photon
- Energy of the recoil electron and scattered photon
- For best reconstruction, also want to measure direction of recoil electron
- Scattered photons tend to scatter at right angles to the polarization vector

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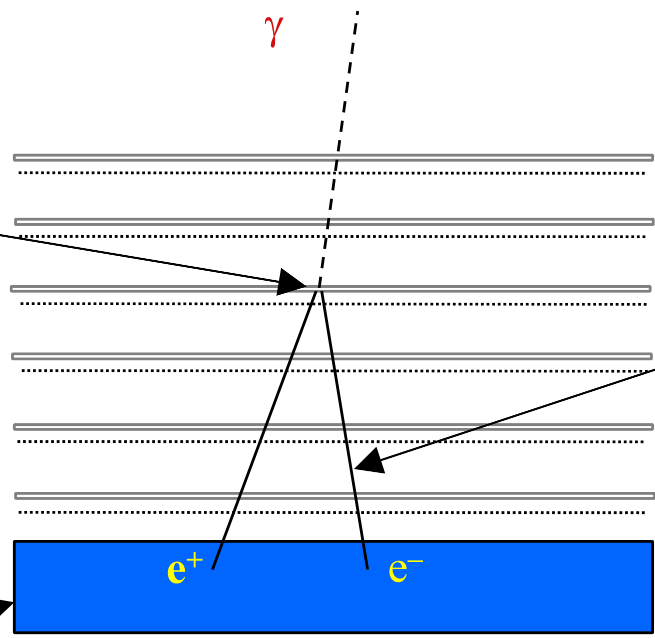
Pair Production

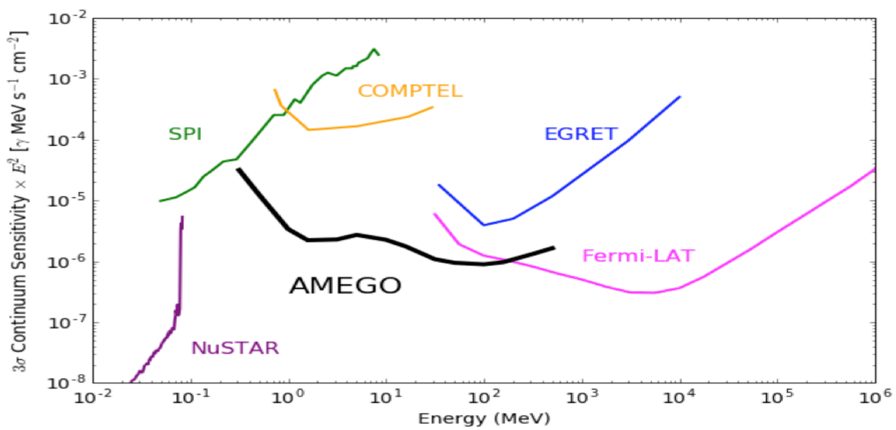
photon converts to an $e^+ e^-$



The directions of the charged particles are recorded by particle tracking detectors, the measured tracks point back to the source.

The energy is measured in the calorimeter

What do we want to build?



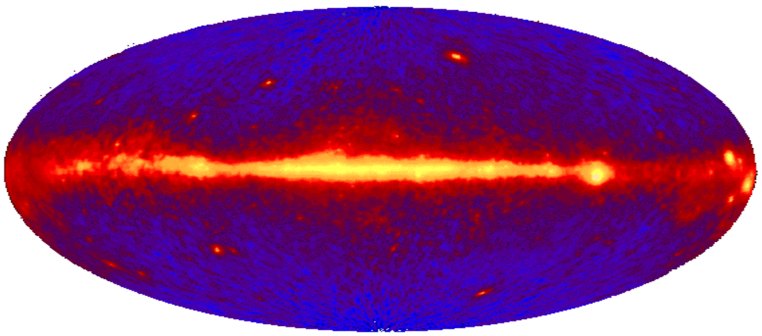
NASA Probe-class mission

- **AMEGO: All-Sky Medium Energy Gamma-ray Observatory**
  - Compton-Pair space telescope
- Observing strategy: all-sky survey multiple times per day
- Wide-aperture instrument with Field-of-View 2.5 sr
- Sensitivity: 10 – 50x better than COMPTEL at 1 MeV
- Energy range: 200 keV -> 10 GeV
- Angular resolution: 5x better than Fermi LAT at 20-100 MeV
- Polarization sensitivity in 0.3 – 5 MeV range
- Well-understood and tested technologies with space heritage

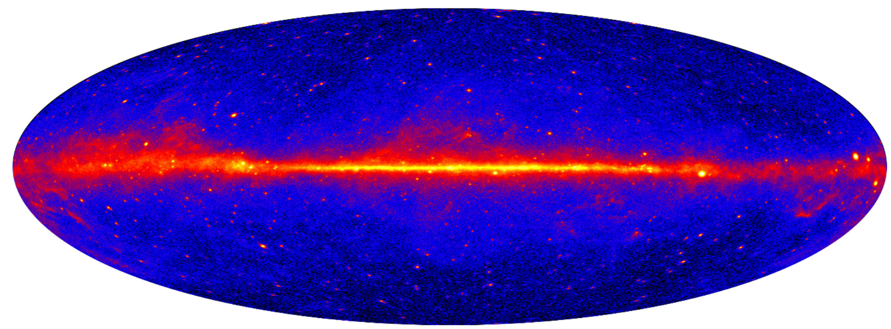
What we can expect from AMEGO

- The MeV domain is one of the most underexplored windows on the Universe. From astrophysical jets and extreme physics of compact objects to a large population of unidentified objects, fundamental astrophysics questions can be addressed by a mission that opens a window into the MeV range.

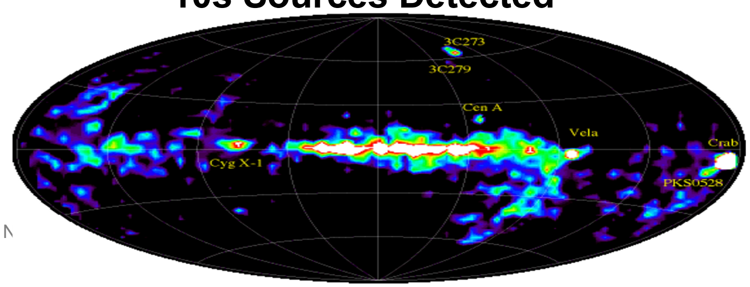
EGRET All-Sky Map Above 100 MeV
~200 Sources Detected



***Fermi*-LAT All-Sky Map Above 1 GeV**
~3000 Sources Detected



COMPTEL All-Sky Map 1 - 30 MeV
~10s Sources Detected



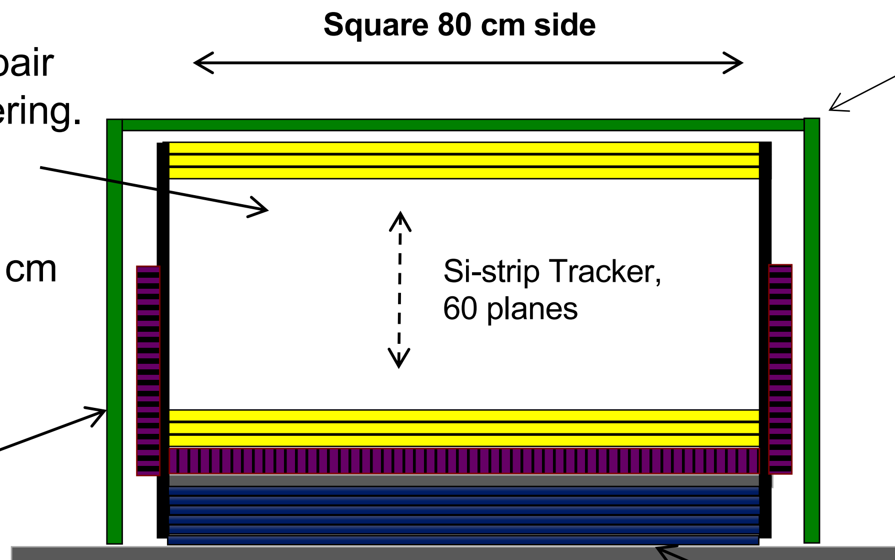
We expect at least a similar progress as from EGRET to Fermi-LAT

AMEGO Concept

Tracker

Incoming photon undergoes pair production or Compton scattering. Measure energy and track of electrons and positrons

- 60 layer DSSD, spaced 1 cm
- Strip pitch 0.5 mm



ACD

Plastic scintillator tiles with SiPM readout

CZT Calorimeter

Measure location and energy of Compton scattered photons

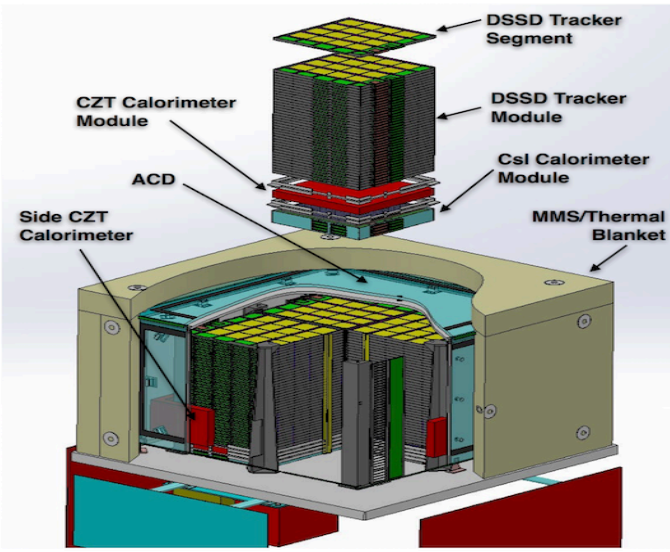
- Layer of 0.6 cm x 0.6 cm x 2 cm bar CZT

CsI Calorimeter

Extend upper energy range

- 6 planes of 1.5 cm x 1.5 cm bars

AMEGO Concept



Instrument concept:

- Optimized performance in 1 MeV – 100 MeV range, with full range 0.2 MeV – 10 GeV
- Simplicity, long-term (~10 years) reliability, max use of already space-qualified technology
- Sensitive to both γ-ray interactions: pair production and Compton scattering
- Minimized amount of passive elements in detecting zone of the instrument (no passive γ-ray converters as in LAT)
- Use fine segmentation of all detecting elements to provide the best particle tracking and event identification

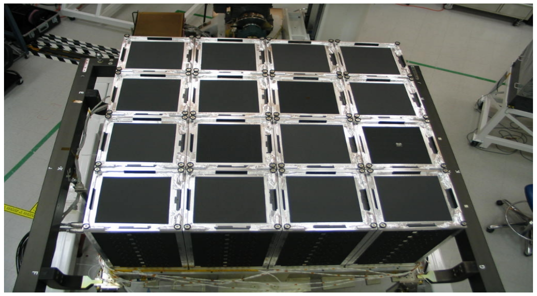
Mission concept:

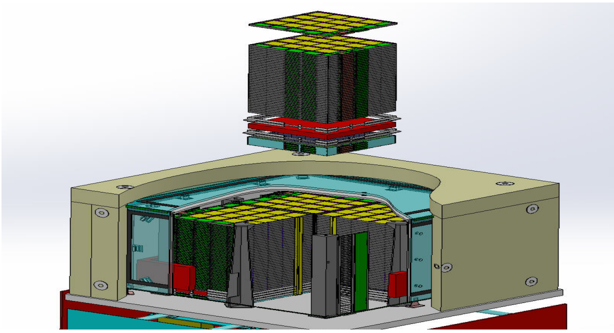
- Orbit: circular
- Altitude: 500 km
- Inclination: 5-10º
- Data downlink: Ka band/TDRSS

AMEGO Instrument Summary

Energy Range	0.2 MeV → 10 GeV
Effective Area	100 - 200 cm^2 < 10 MeV, 200 - 1200 cm^2 > 10 MeV
Angular Resolution	3º (1 MeV), 10º (10 MeV), ~1º at 1 GeV
Energy Resolution	<1% below 2 MeV; 1-5% at 2-100 MeV; ~10% at 1 GeV
Field-of-View	2.5 sr
Sensitivity (MeV s^{-1} $cm^{-2)}$	4×10^{-6} (1 MeV); 4.8×10^{-6} (10 MeV); 1×10^{-6} (100 MeV)
Dimensions	1 m x 1 m x 0.7 m (sensitive volume)
Mass	<1000 kg (science payload)
Power	<1000 W (science payload)

From Fermi-LAT to AMEGO





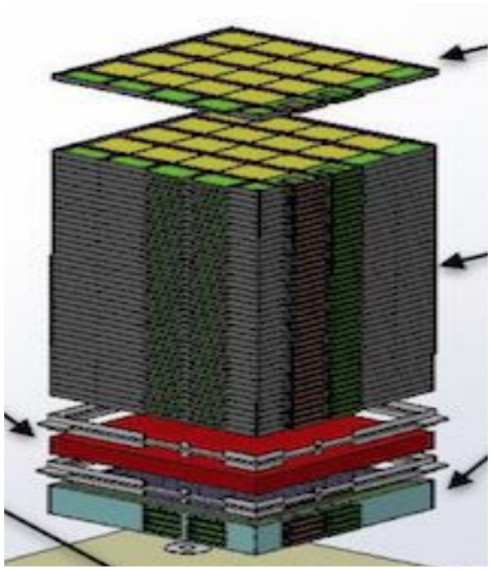
- AMEGO Tracker:
  - No conversion foils -> reduce multiple scattering
  - No interior towers -> avoids technical challenges in electronics mechanical design to minimize tower spacing
  - Spectroscopy readout of Si tracker (for energy measurement)
  - Double-sided Silicon strip detectors (measures x- and y- coordinates, lower energy threshold)
  - Minimal passive material inside the towers
- AMEGO Calorimeter
  - Added CZT calorimeter for more precise position and energy measurement of scattered Compton photon
  - CsI read out with SiPM -> better position and energy resolution, lower energy threshold

AMEGO Subsystems

- Silicon Tracker
- CZT Calorimeter
- CsI Calorimeter
- Anti-coincidence detector (ACD)

Silicon Tracker

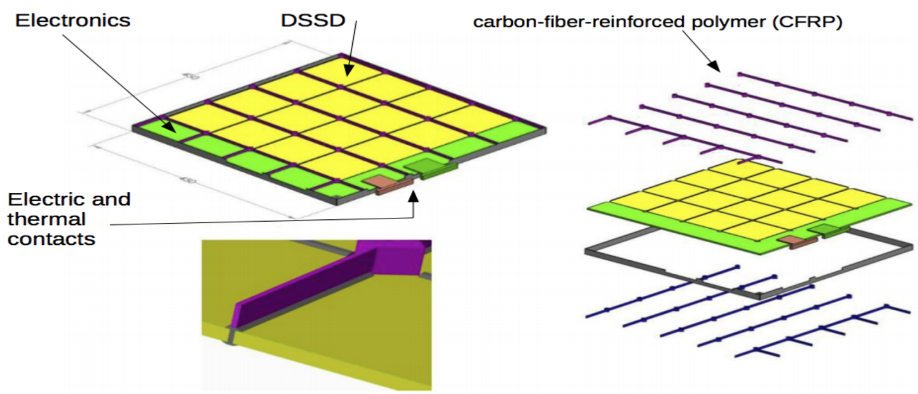
- Using double-sided silicon strip detectors (DSSD).
- Design: Four towers comprising 60 layers of a 4x4 daisy-chained DSSDs
- Each DSSD wafer 10 cm x 10 cm
- Electronics on the edges
- Compton requirements:
  - DSSDs required for position measurement of Compton scatter
    - Low-energy Compton electrons may not penetrate two-single sided detectors
  - Spectroscopy readout of each strip to measure energy



Si Tracker

See iPoster (Thursday 9A): Development and Testing of the Si Tracker (S. Griffin)

- Daisy-chaining four DSSDs may produce too much noise due to parasitic capacitance.
- Affects detector performance, especially at low energies.
- Upcoming tests with 7-element "L-shape" prototype:
  - Proxy for a 4x4 segment
  - Can measure parasitic capacitance and approximates the noise of a 4x4 layer.
  - Position & energy resolution using radioactive sources (critical to event reconstruction systematics).



- Silicon production started at Micron
- 500 μm thick, 60 μm strip width, 192 strips per 10 cm side (500 μm)
- Significant amount of work went into developing the mask such that wafers could be daisy chained

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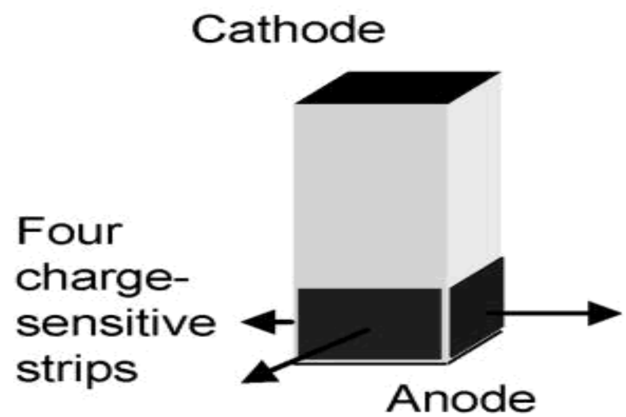
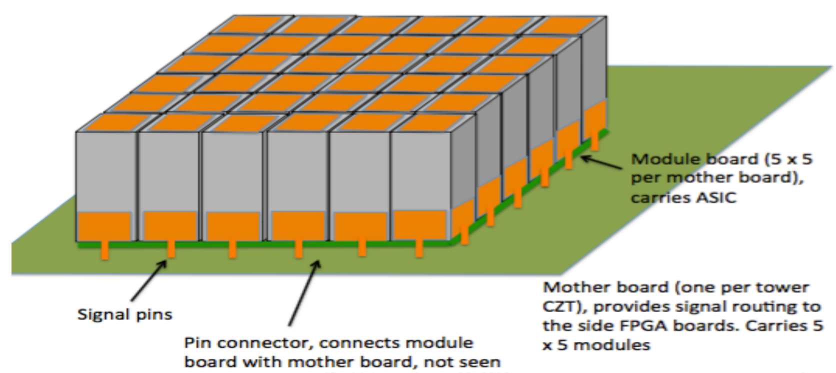
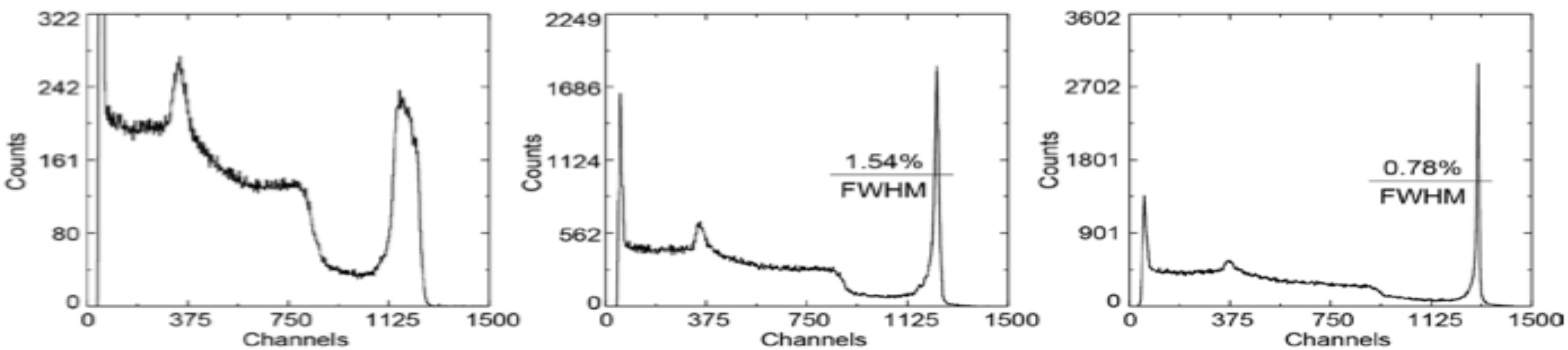
Cadmium Zinc Telluride (CZT)

- CZT is already a space-qualified semiconductor detector for X-rays and gamma rays, in use on Swift and NuSTAR.
- On AMEGO, CZT calorimeter positioned under and around all four sides of the Si tracker.
- Approach: attach charge-sensitive strips around the sides of the crystal near the anode, acting as a virtual Frisch grid to shield the anode. Amplitudes of the signals from the side strips determine x- and y-coordinates of photon interaction. Drift time and cathode to anode ratio determine z-coordinate.
- Segmented calorimeter: 6x6 CZT bars, each 0.6 x 0.6 cm x 3 cm (~2 X_0)
- Expected energy resolution is <1% at 662 keV, 2-3% at 5 MeV
- Expected position resolution <0.5mm at <1 MeV, 2-3 mm at 5 MeV





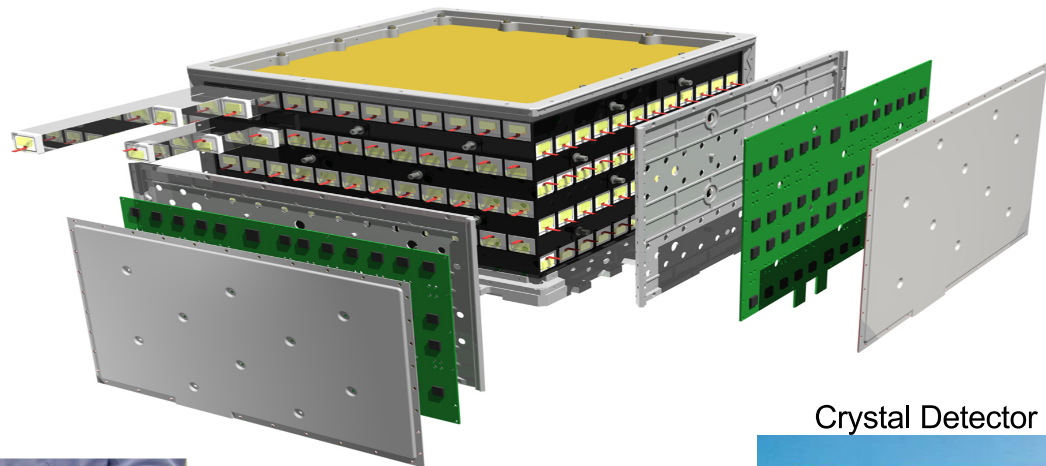
Energy resolution for CZT drift bar detector



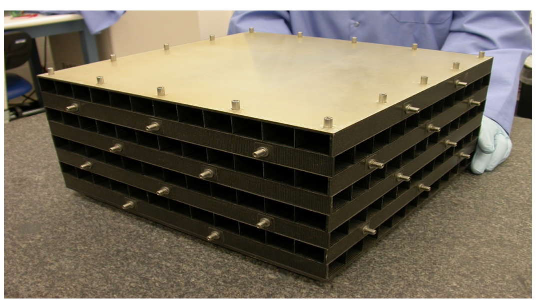
- Results courtesy of BNL collaborators (A. Bolotnikov, et al., *IEEE TNS*, 59(4), 1544-1551, 2012).
- Left figure shows raw spectra of the ^{137}Cs measured with CZT bar
- Center figure corrected for drift time, right figure shows with 3-d correction applied.
- Initial results at NASA-GSFC shows similar promising results.

CsI(Tl) Calorimeter

Leverage experience from LAT Calorimeter design and development

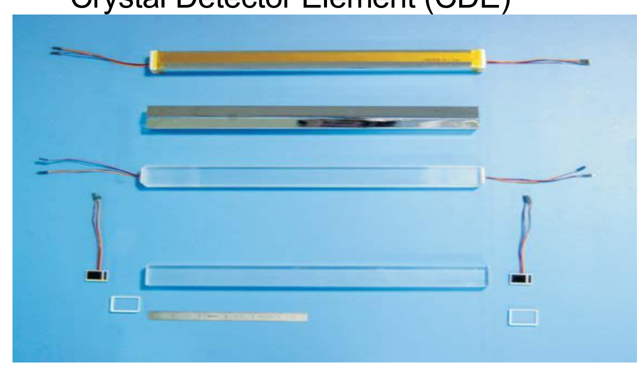


Modular assembly



Carbon composite mechanical structure

Crystal Detector Element (CDE)



See Poster (Thursday 5:30P): Development of the CsI Calorimeter Subsystem for AMEGO (J. E. Grove)

SiPM to PIN photodiode comparison

Compare to test data from Fermi LAT calorimeter development

Fermi LAT CDEs

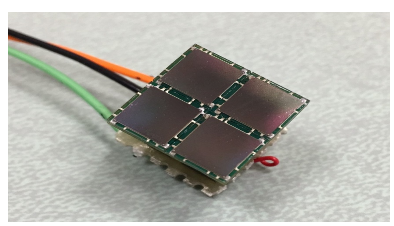
- 20x27x326 mm CsI(Tl) crystal
- Dual PIN photodiode on both ends
  - 1 cm^2 and 0.25 cm^2 diode areas
- Tetratex diffusive wrap test

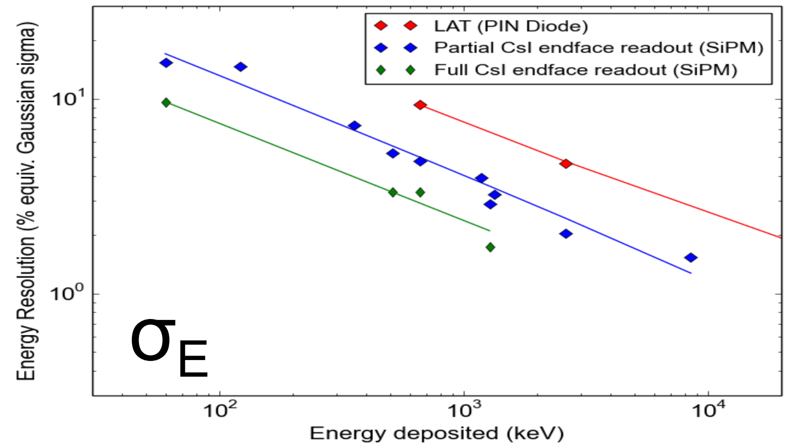
Test CDE

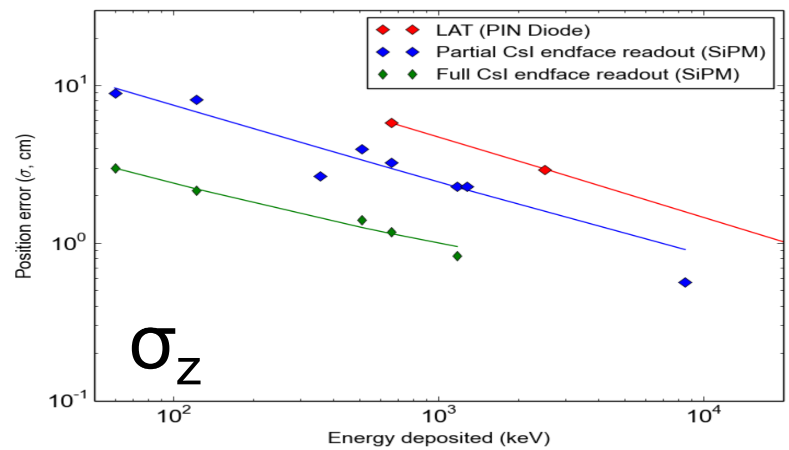
- 15x15x320 mm CsI(Tl) crystal
  - (~1996 purchase from GLAST development)
- SiPM on both ends
  - One 6x6mm or 2x2 6x6mm array SensL C-series
- Tetratex diffusive wrap

Conclusion – Replacing PIN with SiPM:

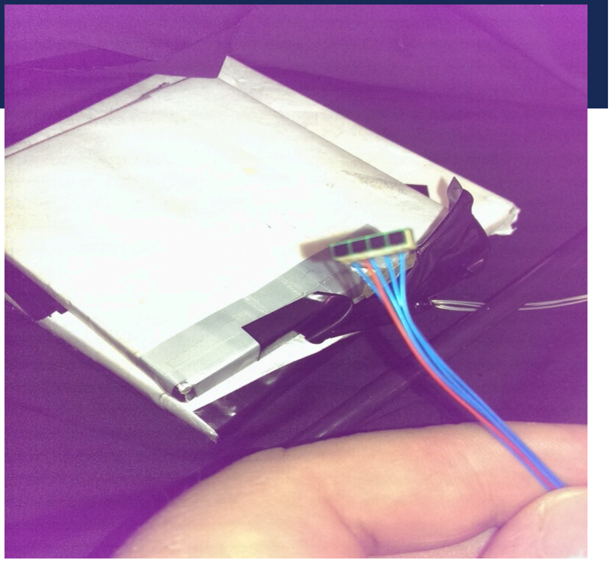
- Improves calorimetry for ~10-100 MeV pair telescope
- Enables ~1-30 MeV Compton telescope with modest channel count, macroscopic crystals



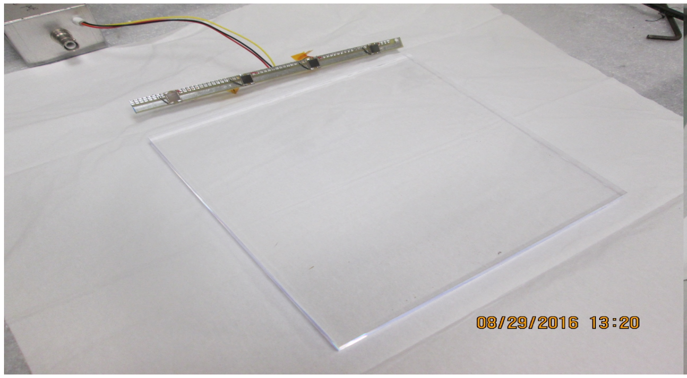


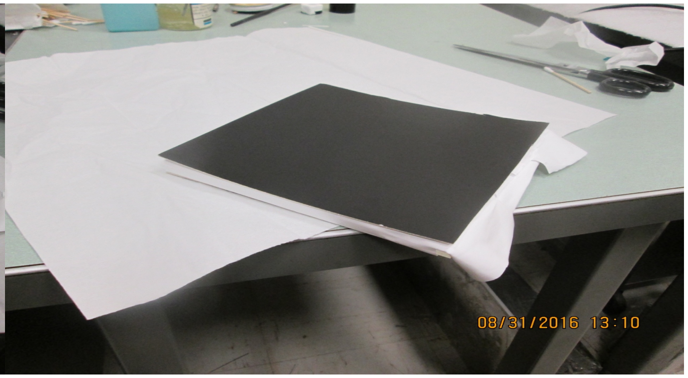


Anti-Coincidence Detector (ACD)



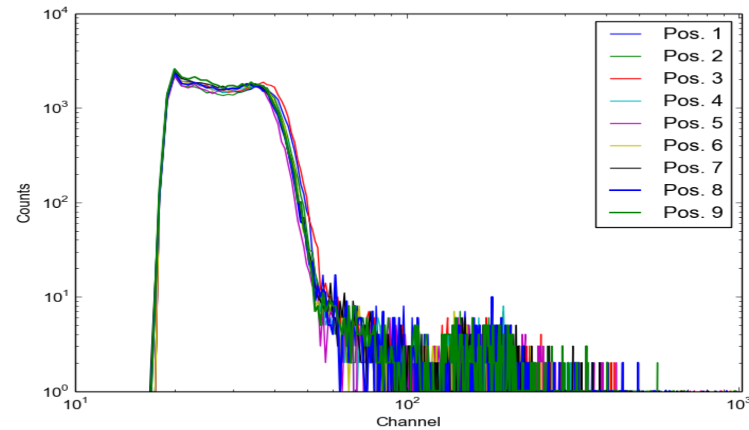
- Work currently underway at NRL (bottom) and NASA-GSFC (right)
- Testing SiPM readout of plastic scintillator sheet
  - Eljen (EJ) 200
  - NRL: 180 mm x 180 mm x 10 mm
- Wrapped white diffuse reflector on all sides, then with black cardboard/electrical tape.
- NASA-GSFC exploring the value of waveguides to improve light collection

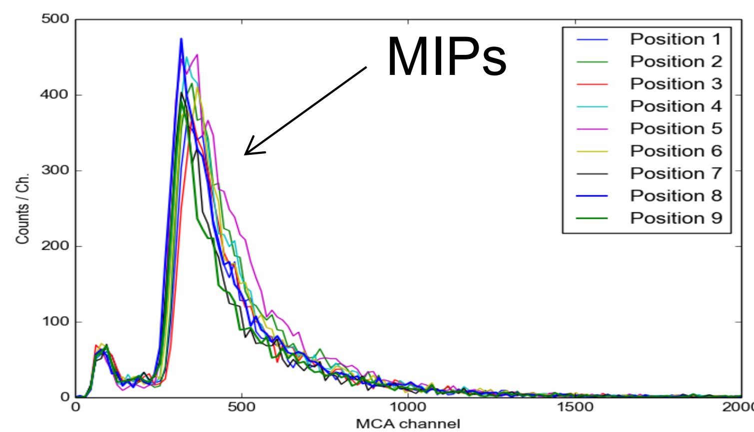




ACD performance

- Top plot shows the NRL ACD with SiPM readout for collimated ^{137}Cs mapping out a 3x3 grid.
- Average channel of the ^{137}Cs Compton Edge (477 keV) demonstrates that the uniformity does not deviate by more than 5%.
- Measured minimum ionizing particles (MIPs) passing through the ACD plastic.
- Cosmic-ray muons provide ‘free’ source of high-energy particles, depositing ~1.5 MeV in 10-mm-thick plastic.
- Small chunk of plastic scintillator/PMT as a paddle and required coincidence between the paddle and the ACD plastic to trigger.





Future Work

- NASA APRA currently funding development and testing of the subsystems outlined: Si tracker (PI: J. McEnery, NASA-GSFC), CZT (D. Thompson, NASA-GSFC), and CsI calorimeter (PI: J. E. Grove, NRL).
- Prototyping/testing readout for CZT, daisy chained double-sided Si strip detectors, build and test CsI calorimeter with SiPM readout via ASIC.
- Developing prototype instrument for beam tests and balloon flight in 2018/2019
- Engineering study of full instrument/mission concept
- Robust resources and cost estimate
- Developing and communicating AMEGO science case
- Plan to submit white papers to the upcoming decadal survey

Acknowledgements

Work at NRL is sponsored by the Chief of Naval Research (CNR), NASA-APRA (NNH14ZDA001N-APRA), and NASA-APRA (NNH15ZDA001N-APRA)